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Looking Inside the Brain—Glimmerings of Insight from Brain Scan Research and the Neurobiology of Reading

Did you know that some neuroscientists believe that they have not only found the location in the brain for dyslexia but also the cause of it? Did you know that they think your teaching practices might "cure" dyslexia if you provide intervention with dyslexic children when they are young enough? Wouldn't it be ironic if part of the reading problem is the lack of appropriate spelling instruction? Brain scan research addresses each of these questions directly. In my view, brain scan research is not an exact science and it does not tell the whole story of how reading works. It might, however, provide some glimmerings of insight.

First of all it must be acknowledged that the brain is incomprehensibly complex—admittedly incomprehensible even to most neuroscientists. Your brain has about 100 billion neurons or nerve cells, for transmitting electrical impulses, which is comparable to the number of stars in the universe (Sousa 2002). Secondly, like a fingerprint, every brain is different. Nonetheless, underneath this dazzling complexity there are core patterns that may be detected by brain scans, which are a kind of map of the brain (Byrnes 2001). While every reader's brain is different, with one's own unique working vocabularies and word modules in the brain, and different experiential memories and worldviews to bring to the reading process, there is commonality in the way people experience reading. We all very likely have similar systems of interacting modes for processing orthographic, phonological, syntactic, and semantic aspects of language; but then again, perhaps skilled readers, beginning readers, and dyslexics who have learned to read have differences in their neurological circuitry.

Some neuroscientists believe that brain scan work is helping to unlock some of the mysteries of reading and to provide important guidance for teaching it.

It's interesting to take a brief look at the ascendancy and newness of brain scan research for reading. Beginning in the early 1980s, neuroscientists began using a technology called positron emission tomography (PET) to see the brain's activity by measuring the blood flow in specified cerebral regions, raising the observation of the brain up a notch, so that for the first time, a brain scan might not only show a perfect picture of the human brain's structure, but also aspects of the brain's function during cognitive processes such as reading. When an area was activated, the blood flow increased, and by injecting radioactive compounds into the bloodstream, the scientists could record regional distribution of radioactivity. For the first time, neuroscientists were able to see "reading areas" of the brain performing various reading-related processes. PET was more recently replaced by a technology called *functional* magnetic resonance imaging (fMRI), which goes beyond the MRI picture of the brain. You are probably familiar with magnetic resonance imaging (MRI), which is commonly used in medicine to produce computer-processed, high-contrast images of the body's anatomy. In contrast, fMRI shows which areas are *functioning* by monitoring the magnetic properties in blood and recording activation and increased blood flow in an area where neurons are firing. Unlike PET technology, no injections are required for fMRI technology (Shaywitz 2003).

A benchmark crosscultural study was published in 2001 entitled "Dyslexia: Cultural Diversity and Biological Unity" (Paulesu et al. 2001) in which the researchers used PET scans to determine if dyslexia was biological or cultural. Dyslexia is any neurologically based specific reading disability. This study identified subjects with developmental dyslexia as opposed to acquired alexia, the latter being a loss of reading ability resulting from a stroke, tumor, or traumatic injury to the brain. Did normal readers' brains function differently than developmental dyslexics who had learned to read? Were dyslexics who had learned to read activating different regions of the brain? The answer was "yes." Not only did the normal readers show greater activation in all brain regions associated with reading, but they produced different brain scan profiles than did the dyslexic subjects who could read. The area of difference seemed to be an area associated with spelling. Does the brain of a skilled reader have some mechanism for storing and retrieving the exact spelling of a word and could this possibly not be activating in the brain of a dyslexic? The study found commonality in brain scans among normal readers across languages and in dyslexic readers across languages even when the languages had vastly different spelling systems. One of the interesting facts to come out of the report was that English was much harder to read and to spell than a language like Italian because readers of Italian only have to know thirty-three spelling combinations for its sounds, while the English reader has to know 1,120 spelling combinations for the sounds of English (Kher 2001, 56), presenting a formidable challenge to the beginning reader or writer of English. The implication is that teaching and guiding children who are emerging as

English readers requires great focus on how English letters represent the sounds of our language. Thus, the English spelling system, because of its complexity, may be a big part of what needs to be learned so that beginning readers may gain ability to read words instantly and to read with fluency. My own reading of the Paulesu study kept bringing me back to the importance spelling has for reading. Like the Seidenberg and McClelland model, this early important brain scan study showed that spelling plays an enormous role in skilled reading. Why is it then, that we tend to gloss over spelling when teaching literacy in elementary school?

The Paulesu study made me wonder about the role spelling plays in automatic word recognition as well. To me, the study implies that there may in fact, be a region where the brain stores memories of exact spellings of words (like *regatta*) enabling expert spellers to "see spelling in their mind's eye" (Gentry 2004). Paulesu and colleagues reported inactivity in areas linking language to visual cues in the dyslexic brain, which may explain why dyslexics are notoriously poor spellers. In my view there are three kinds of spellers—people who learn to spell with relative ease, people who seem to be naturally poor spellers, and people who are uneducated spellers. The latter category is eliminated by decent instruction, leaving two categories—natural spellers who acquire the skill if they work at it, and about one-in-five naturally poor spellers who may never be expert spellers no matter how hard they try. I believe the main difference between a naturally poor speller and an expert speller is that the expert speller is activating an area of the brain that can "see" the word in his or her mind and the poor speller cannot "see" the word because the area linking language to visual cues in not activated. Instead, a compensatory system of reading is being used, employing other areas of the brain. Is there an area of the brain on the boundary between language and visual processing where skilled readers eventually activate correct spellings automatically—an area that links language to visual cues? The Paulesu study seems to point in this direction. I am an atrocious speller myself, and probably a dyslexic who has learned to read. Suppose I'm writing and all of a sudden I need the three-syllable verb that starts with *r-e* and means to call past events or experiences to mind. Sometimes the only clue I have in a situation like this it to spell it like it sounds. I cannot "see" the word in my mind; however, if I see *reminisce* in print, unquestionably I recognize it. My attempt at spelling it, however, is likely to be something like *remeness,* which is so far off it is not even recognized by a computer spell checker.

It's also interesting to report that my reading is slow and I am conscious of a great deal of subvocalization. I usually pronounce every word in my mind when I read. Many readers are capable of reading much faster than I can—because they don't subvocalize! Very likely, I am activating different than normal left-sided brain circuitry for reading and spelling; nevertheless, the reading part works for me. It just takes me more time. Even though my reading is slow, I am an excellent reader. No matter how hard I try, however, I have been unable to become an excellent speller. The Paulesu study suggests an important spelling/

reading connection between spelling and reading, and that the role of spelling in literacy is central. (Though, literally, the activation of perfect spelling is *posterior* according to brain scans!)

Probably the best known of the brain scan work that is influencing reading education is work by neuroscientist and professor of pediatrics, Sally Shaywitz, and her colleagues at the Yale Center for the Study of Learning and Attention, reported in her book *Overcoming Dyslexia* (2003). Shaywitz and her colleagues' fMRI studies have been focused on creating a reading map of the brain by charting the neural circuitry for reading. Initially, Shaywitz identified specific neural sites for sounding out words (77). Then her work focused on looking at differences in brain activation patterns for dyslexic versus normal skilled readers. This work, according to Shaywitz, has uncovered the basic brain mechanisms underlying reading, not only leading to knowledge of "exactly where and how dyslexia manifests itself in the brain" (4), but by contrasting dyslexic and normal readers' brain scans she believes the basic neural pathways of reading have been identified (10). She found dyslexia to be specifically localized within the phonologic component of the language system, the part of the brain "where the sounds of language are put together to form words and where words are broken down into their elemental sounds," and she calls this part of the brain the "word form area" (40). Her findings indicate that the upper levels of language processing, those for semantics, syntax and the basic neural sites for speaking and understanding language, are not affected by dyslexia. The problem is in the lowest level, the phonologic module where sound elements of language are mapped, or chunked, onto spelling (41). While reading does rely heavily on brain circuits already in place for spoken language, that brain circuitry functions normally in dyslexics. Dyslexics have no problem with higher-order processes needed for comprehension such as vocabulary, use of context, reasoning, and deriving meaning. In fact, according to Shaywitz, dyslexics often exhibit particular strengths in comprehension, problem solving, reasoning, critical thinking, vocabulary, and general knowledge (53). Indeed, dyslexics have not been shown to have visual defects, as is widely reported; they don't typically transpose letters or write backwards. Shaywitz says, in fact, "reversals are irrelevant to the diagnosis of dyslexia" (101).

The brain scan studies revealed that the problem resides in the basic circuitry for linking letters to sounds—Shaywitz alternately calls this region of the brain "the word form area," "the left posterior brain region," or "the occipito-temporal area." Since spelling is linking letters to sounds to form words, think of the area as "the automatic spelling circuitry," in other words, the area of the brain that allows expert spellers to "see words in their mind's eye." It's interesting to note this association of the spelling circuitry with dyslexia because severe spelling disability is a telltale sign of dyslexia.

The problem leading to dyslexia, according to Shaywitz, occurs at this lowest level of processing language, the decoding level, or spelling level, where printed words are translated into the phonetic code, that is, where text becomes

the sounds of human language in the mind, and then is accepted and processed by the higher-level neural circuitry already in place for processing spoken language (51). In essence, dyslexia happens at the letter-chunking level. In fact, that's what English spelling is—it's chunking groups of letters to represent sounds. Part of the work of the brain is to sort through enormous amounts of information and find regular patterns within it. That's exactly what it does with spelling and reading, which turns out to be one of man's greatest intellectual accomplishments—figuring out how a language's spelling system chunks into representations of the sounds of spoken language. The brain discovers the chunking system for making alphabetic letters represent word parts and words. It's especially challenging for English because English has over one thousand combinations for its forty-four sounds.

The glitch associated with dyslexia happens in the reading process after the brain sees the words on the page, at the point when the brain tries to convert the letters into their sounds, by chunking. The problem occurs before the brain engages its innate abilities to process speech into meaning. The location of the glitch is in the phonologic component of the language system, more precisely, the automatic spelling area, the basic circuitry for chunking letters to sounds.

> The phonologic model tells us the exact steps that must be taken if a child is to go from the puzzlement of seeing letters as abstract squiggly shapes to the satisfaction of recognizing and identifying these letter groups as words. Overall, the child must come to know that the letters he sees on the page represent, or map onto, the sounds he hears when the same word is spoken. (44)

Shaywitz believes that the neuroscientists, with the technology of brain scan research, have been able to identify precisely where in the brain the child chunks the letters he sees on the page to the sounds he hears when the same word is spoken. It's the area that transcribes chunks of letters into sounds. This brain area, the word form area (occipito-temporal area), which I like to think of as the automatic spelling area, is where skilled readers recognize words automatically. (You can see it designated as Area C in Figure 2.1.) Dyslexics do not activate this area. The dyslexics who do learn to read activate different areas, including more in the front of the brain and often on the right side of the brain, which is unusual since the unimpaired skilled reader primarily uses a left-brain reading system. Shaywitz believes that dyslexics who do learn to read use a compensatory system of reading networks, that is, they activate different areas and exhibit different qualities for reading than do unimpaired skilled readers. They are slower at reading, since they can't use the word form area to recognize words automatically, and they use other areas of the brain to do the word form area's work. Dyslexics are also very poor spellers, perhaps because they don't activate Area C, the word form area, where the brain houses word modules with visual representations of words and their exact spellings. Instead of chunking *reminisce*

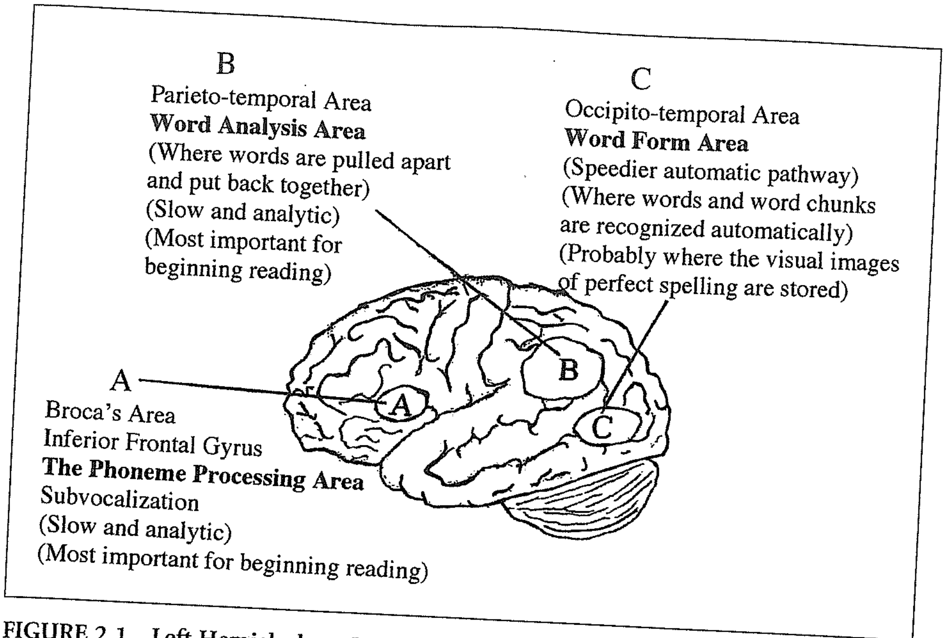

FIGURE 2.1 Left Hemishphere Brain Systems for Reading
Adapted from S. Shaywitz, *Overcoming Dyslexia.* Alfred Knopf, 2003. Reported in J. Richard Gentry, *The Science of Spelling: The Explicit Specifics That Make Great Readers and Writers (and Spellers!)* (Heinemann, 2004).

as *reminisce,* they may spell it as *remeness.* Because they can't "see" it in the mind, they must spell it like it sounds.

So who gets the blame for dyslexia? Shaywitz says it is a neurological glitch, perhaps even related to a set of genes (though identical twins don't necessarily share the condition), and that the glitch likely takes place during fetal life—during embryonic development when the brain is hard-wired for language (67). The glitch is confined to the wiring of the word form (spelling) area, Area C. One promising aspect of her work is that preliminary studies involving children who are just learning to read indicate that, with the proper instruction, the brain can fix itself—that is, it can bypass the glitch and activate Area C, the word form area, even in children who have the genetic predisposition to be dyslexic. Fixing itself requires early intervention, however, when the brain is plastic and malleable for rerouting neural systems (30), which apparently is best achieved around the ages of five and six. (Most learning disabilities in the United States are identified between the ages of eleven and seventeen, which is too late. [Gorman 2003])

Interestingly, both the Seidenberg and McClelland model and the Shaywitz brain scan studies have tended to focus mostly on skilled versus poor reading, or in the case of Shaywitz' work, skilled versus dyslexic readers. I think an aspect of the brain scan work equally promising for helping educators understand how

best to teach reading manifests itself in glimmerings of insight related to beginning versus skilled reading. If we think about beginning reading as we focus on Shaywitz' report of how left-side reading works, we get some of these glimmerings of insight. Then we can begin to develop a separate model for beginning reading.

Look at Figure 2.1, a model of the left-side brain system for reading in the skilled, unimpaired reader. There are three areas activated for reading, which I have designated A, B, and C. In the skilled reader, most of the brain activation for reading takes place in the back of the brain incorporating areas B and C. Area C is the word form or spelling area, which as we have seen, has been identified as the area for automatic word recognition and perfect spelling. It's the area that is not activated in dyslexics and for most impaired readers it's the area of the dictionary in the brain, holding the word module for every word one has in one's vocabulary. Once activated when seeing a word on sight or thinking of a word to be written, this area produces the word's sound, its meaning, and, in expert spellers, its exact spelling. When one reads, this area reacts instantly to the whole printed word as a pattern by identifying the word automatically on sight (79). Since the brain works by drawing analogies and finding regular patterns, I suspect not only automatic recognition of words but automatic recognition of spelling patterns—the *sail* in unas*sail*able, for example—is extremely important for reading, especially for reading polysyllabic words. The brain is actively seeking out these chunks of spelling patterns.

Of course, beginners don't have very many words in Area C and it's only at the later phases of beginning reading that they are able to seek out chunks of spelling patterns and analogize. Shaywitz believes beginners must first analyze and read words correctly a number of times in order to form an exact neural model of that specific word to be permanently stored in Area C. Areas A and B, which are slow and analytic and most important for beginning reading, are responsible for that work. So the distinction between beginning reading and skilled reading made by the brain scan studies is that they are entirely different systems for reading, involving activation in different areas, or as Shaywitz calls it, two different pathways. To use my metaphor, tadpoles and frogs:

> Imaging studies have identified at least two neural pathways for reading: one for beginning reading, for slowly sounding out words, and another that is a speedier pathway for skilled reading. (78)

According to Shaywitz, the areas that are activated most for beginning reading are areas A and B. Area A, in the left inferior frontal gyrus in Broca's area, plays a role in slow word analysis. This part of the brain is activated for articulating spoken words, and during reading for subvocalizaton, that is, when a reader repeats words in her mind as she reads (81). Shaywitz believes this area plays an important role in beginning reading for processing sounds. For example, it's where rhyming and phoneme manipulation take place.

Area B, located on the left side in the middle of the brain a little above and behind the ear in the parieto-temporal region, is used by the beginning reader for word analysis. Shaywitz explains Area B this way: "Slow and analytic, its function seems to be in the early stages of learning to read, that is in initially analyzing a word, pulling it apart, and linking its letters to their sounds" (79). I presume skilled readers would activate this area if they encountered an unknown new word. But skilled readers mostly use Area C, which Shaywitz calls the "express pathway," which instantly and automatically activates a word form in the brain that not only identifies the word on sight, but its sound, its meaning, and its spelling. Shaywitz' work has revealed that the best readers show higher levels of activation of Area C, establishing "a strong link between reading skill and reliance on the word form area" (81). What can we do in our teaching of beginning readers to help get this word form area activated? To lay the foundation to better answer this question, let's move from the inside to look at what happens outside the brain as a beginning reader reads.